

Acid Rain: A preliminary estimate of the risk to Ontario's inland fisheries.

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of Fisheries and Aquatic Sciences 1622

November 1981

ACID RAIN: A PRELIMINARY ESTIMATE OF
THE RISK TO ONTARIO'S INLAND
FISHERIES

by

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ABSTRACT

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The lake inventory database of the Ontario Ministry of Natural Resources, in conjunction with counts of numbers and areas of lakes by watershed and size, are used to estimate the quantity of Ontario's inland fishery resources which are at risk from acid precipitation. The inventory data include conductivity, pH, morphometry and fish community information. These data are taken to be representative of the total, after correction for the over representation of brook trout, Salvelinus fontinalis. Lakes are classified according to acid stress, sensitivity, and fish community.

The results indicate that up to 350000 hectares of lakes (16000) are in areas where the precipitation pH is low and the lake waters poorly buffered. The lakes in this condition mostly contain salmonid dominated fish communities, lake trout, Salvelinus namaycush, and/or brook trout. If these lakes are acidified to the point where they are incapable of sustaining fish communities, Ontario stands to lose more than 30% of some key salmonid fisheries.

Among the 16000 lakes, there are 4600 which must be considered as being already acidified. Many of these lakes are small and are in the Sudbury-La Cloche region, where previous studies have identified many larger lakes as having been acidified, predominately as a result of local smelter operations.

RÉSUMÉ

La base des données du répertoire des lacs du ministère ontarien des Richesses naturelles est utilisée avec les chiffres sur le nombre et la superficie des lacs par bassin versant et par taille pour évaluer la quantité des ressources halieutiques intérieures de L'Ontario menacées par les pluies acides. Les données du répertoire comprennent la conductivité, le pH, la morphométrie et des renseignements sur les stocks de poisson. On considère que ces données sont représentatives du total, après correction de la représentation exagérée de l'omble de fontaine Salvelinus fontinalis. Les lacs sont classés selon leur exposition aux pluies acides, leur sensibilité et leurs stocks de poisson.

Selon les résultats, jusqu'à 350000 hectares de lacs (16000) sont situés dans des régions où le pH des précipitations et le pouvoir tampon des lacs sont faibles. Les lacs de ce type contiennent des stocks de poisson composés pour l'essentiel de salmonidés comme le touladi Salvelinus namaycush, ou l'omble de fontaine. Si ces lacs sont acidifiés au point de ne pouvoir assurer la survie des stocks de poisson, l'Ontario risque de perdre plus de 30% de certaines pêches importantes de salmonidés.

On doit considérer que 4600 de ces 16000 lacs sont déjà acidifiés. Un grand nombre d'entre eux, de petite taille, sont situés dans la région Sudbury-La Cloche où des études antérieures ont montré que de nombreux grands lacs avaient été acidifiés, surtout à la suite des activités métallurgiques locales.



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Acid Rain: A Preliminary Estimate of the Risk
to Ontario's Inland Fisheries
by Charles K. Minns

INTRODUCTION

Precipitation presently falling on a large part of Ontario has a pH of 4.5 or less. Since the waters of many lakes on the Canadian Shield have a minimal capacity to neutralise mineral acidity, the low pH of the rain and snow represents a considerable threat to the survival of fish communities in those lakes. A significant loss of fish habitat has already occurred in the Sudbury-La Cloche region as a result of local smelter operations (MOE, 1978; Beamish and Harvey, 1972). Evidence from Scandinavia and Sudbury strongly indicates that, in the absence of decisive measures to reduce emissions of sulphur and nitrogen oxides in Canada and the United States, the area affected will grow and an increasing number of lakes will be acidified to the point where fish can no longer reproduce or survive.

To date, there have been no published estimates of the numbers of lakes already in different stages of acidification and the number that might be acidified in the future. The purpose of this study is to provide a systematic estimate of the area and number of lakes that are at various stages of acidification and that might be expected to become acidified. Also, this study attempts to show the potential consequences to the game fish resources of Ontario's inland lakes.

Two data sets are used to derive these estimates, both emanating from work done by the Ontario Ministry of Natural Resources (OMNR). First, as part of the Ontario Fisheries Information System (OFIS), OMNR maintains a lake inventory database. This database is a computer file of data on the morphometry, limnology, and fish species composition of many lakes surveyed by OMNR. Currently (September 1, 1980), the database holds partial information on 6393 lakes. Second, Cox (1978) produced a detailed estimate of the area and number of lakes in the province of Ontario. Total areas and numbers of lakes are reported for eight size categories ($>10^6$ to $<10^1$ hectares by order of magnitude) by primary through quaternary watershed divisions, as laid out by the Water Survey of Canada.

The basic assumption for this analysis is that the lakes of the OFIS database are a representative sample of the total population of lakes as reported by Cox (1978). This assumption is tested by comparing the estimated abundance and distribution of certain fish species with that considered to be the known by OMNR:- brook trout, lake trout and walleye.

Summaries are prepared with respect to designated acid stress, lake sensitivity, and fish community categories, and the significance evaluated. Where uncertainties exist, there has been a conscious effort to err conservatively.

As an aside, some analysis is directed to the question of whether or not dystrophic lakes might influence the summarisation procedure.

METHODOLOGY

Input Data

For the purpose of the analysis, a data file was extracted from the OMNR Lake Inventory database. For each lake the file included:-

1. Lake name, latitude and longitude;
2. Lake area, hectares and other morphometric data;
3. Watershed code;
4. Volume-integrated conductivity at 25C;
5. Volume-integrated pH (calculated via [H] values);
6. The number of fish species recorded in the lake;
7. A presence/absence record for selected fish species.

Fish Communities

Lakes are classified with respect of their constituent game fish communities. Game fish communities are based on combinations of brook trout (Salvelinus fontinalis), lake trout (Salvelinus namaycush), esocids (pike, Esox lucius, and/or muskellunge, E.masquinongy), centrarchids (smallmouth bass, Micropterus dolomieu, and/or largemouth bass, M.salmoides), and percids (walleye, Stizostedion vitreum vitreum and/or sauger, S.canadense). An additional category identified is that of no fish species recorded. With brook trout, only four distinct communities are used; those associations with lake trout and/or centrarchids only. The occurrence of brook trout in association with other fish combinations are so rare that separate treatment is not warranted. Thus 21 fish communities are

considered (Table 1).

Representativeness

As a first approximation, the inventory lakes are assumed to be representative of the total. By secondary watershed (Figure 1), these areas of surveyed lakes are summed in four lake-size categories - ≥ 1000 , $100 - < 1000$, $10 - < 100$, $1 - < 10$ hectares. The ratio of total area to surveyed area by lake-size category is then used as a multiplier (areas rather than lake numbers are used to give more precise estimates). The individual lakes, when aggregated by other criteria, are first scaled up by the appropriate watershed/size-class multiplier. Thus the set of surveyed lakes within each secondary watershed and size category is assumed to represent the total set of lakes.

This initial assumption was used to estimate the number of lakes containing each of the game fish species, by watershed. The results were compared with figures prepared by C.H. Olver (pers. comm.) for brook trout, lake trout and walleye. Since the lake inventory program has been focussed on brook trout lakes, the majority of such lakes have been surveyed and the estimation method overestimated them by about 10 times. Thus the representation assumption had to be modified.

The second, and final, estimation method is as follows: by secondary watershed, areas are summed by lake size categories for the 17 non-brook trout communities (Table 1). Brook trout lakes (areas $\times 1.42$) are summed separately. The ratio of total area less brook trout area to non-brook trout surveyed are then used as a multiplier. The factor 1.42 is the ratio of the total number of brook trout to surveyed brook trout lakes.

Using this modified procedure, the numbers of lake trout and walleye lakes may be estimated (Table 2). The lake trout figures show good agreement with a bias toward underestimation. The walleye estimate is higher than the 'known' though a good deal of this is due to overestimates in north and northwest Ontario, e.g. in Watershed 4F there are estimated to be 734 lakes compared to a 'known' figure of 31. Generally speaking, the overestimation is in the more remote watersheds while the underestimation is in the south and central watersheds where the acid rain problem is the greatest. C.H. Olver (pers. comm.) considers that the walleye

inventory is incomplete and that the figure of 4500 estimated here is much more likely.

Acid Stress and Lake Sensitivity

To assess the potential impact of acid rain, lakes must be sorted by the intensity of stress from acid rain and by the sensitivity of the lakes. Acid stress levels are defined by the average pH of rain for 1977-78. Isoleths (Figure 1) are derived using data from the CANSAP atmospheric precipitation chemistry monitoring program. The concentration pH is used in preference to absolute hydrogen ion loading since there is much fine-scale regional variation in quantity of precipitation independent of regional variation in rain acidity; areas immediately downwind of the Great Lakes tend to have above average precipitation. Further loadings can vary considerably from year to year because of changes in the volume of precipitation, independent of changes in rain pH. The isopleths (Figure 1) are drawn to follow watershed boundaries for convenience but a deliberate effort is made to err conservatively. Thus, isopleths are generally adjusted southwards, reducing the area subject to the highest stress.

Henriksen (1980) and others have shown that lake sensitivity is best defined by a measure of alkalinity, preferably alkalinity depletion. Although the OMNR lake inventory includes many measures of alkalinity, the methodology used is not sensitive enough to allow its use here. However, Kramer (1978) has shown that there is a high correlation between conductivity and alkalinity, in non-acid-stressed lakes and rivers of Ontario and that the relationship is consistent with theoretical considerations. Conductivity is included in the lake inventory data and is considered to be useful for this analysis. Four conductivity sensitivity categories are delimited (Table 3) based on the categories identified in the Bilateral Research Consultative Group report (Environment Canada, 1978).

Within the conductivity sensitivity categories, subcategories are set up by pH, with cutoffs at 4.7, 5.3, 6.0 and 6.5. Henriksen (1980) has pointed out that in the whole-lake titration of lake waters with mineral acids, there are certain critical pH levels. He used these to identify three lake-types - bicarbonate dominated (pH >5.3) with good fish populations, transition lakes (pH 4.7 - 5.3) with mostly sparse fish communities, and acid lakes (pH <4.7) which are mostly barren of fish.

A pH of 5.5 is generally considered to be the cut off for sustaining various fish species. Additional cut offs are set at pH 6.0 and 6.5. A pH of 6.0 may be taken to represent a level below which, in acid-stressed areas, alkalinity depletion may be already occurring. A pH of 6.5 may be taken as a level above which effect is unlikely in all but the categories with the lowest conductivity and highest acid stress. The stress-sensitivity classification is shown in Table 4. The categories are further grouped into four classes to facilitate presentation of results (Table 4):-

- Class A Acidic lakes incapable of sustaining fish populations
- Class B Impacted lakes, already on the way to be incapable of sustaining fish populations
- Class C High risk lakes
- Class D Moderate risk lakes.

Data Substitution

To allow summarisation by fish community or by other means, the conductivity and pH must be known for each lake. In a number of cases, either one or none of these measures are available. A data substitution procedure is used to fill these gaps, based on a 'nearest neighbour' analysis for fish communities by lake characteristics.

The similarity criteria are established using the results of a discriminant analysis by fish community (no fish and no game fish are combined for this analysis). Morphometric parameters, elevation, conductivity, and pH are used as variables. This analysis is performed overall and not by watershed. The scores on the first two canonical discriminant axes are used to create a substitution selection table.

Within each watershed, the surveyed lakes are summarized by fish community, and average pH and conductivities calculated for a lake with missing data, the first substitution choice being the mean for its community type. In the rare case where there are no data, the mean value for the next most similar community with data is used.

Substitutions are necessary for 8% of the pH values and 34% of conductivity values for 6325 lakes (Table 5). Since conductivity shows very smooth geographic trends, it is considered unlikely that the level of substitutions compromises the analysis.

Dystrophy

Inclusion of naturally acidic dystrophic lakes in this analysis would bias the results by indicating dystrophic lakes as acidified. The policy of OMNR Fisheries Branch is to avoid including dystrophic lakes in the lake inventory surveys since their fisheries are considered unimportant. Thus, there is no estimate or sample of dystrophic lakes in the province. However, it is generally known that there are a number of mostly small dystrophic lakes throughout the province. The lake inventory database was summarized in an attempt to identify dystrophic lakes which may have been surveyed by OMNR.

Of the variables recorded in the lake inventory database there are three which can be used in combination to identify dystrophic lakes; colour, pH, and Secchi depth. Dystrophic lakes might be expected to have a pH below 6.0, a yellow-brown colour, and a low Secchi depth. A frequency table was developed classifying lakes by colour (colourless, yellow-brown, and blue-green), and Secchi depth and pH ranges (Table 6). The fish community composition of those yellow-brown categories thought likely to be dystrophic was partially tabulated (Table 7). The results indicate that very few dystrophic lakes are included in the database and therefore the effect on the analysis will be minimal.

RESULTS

Areas surveyed

The proportion of lakes surveyed increases from north to south in Ontario, and larger lakes are more completely surveyed than small ones (Table 8); a pattern that is to be entirely expected given the distribution of people and of their lake usage. Lakes less than 10 hectares are poorly represented, apart from brook trout lakes, but they only represent a small proportion of the total aquatic resource.

There are five watersheds in the far north for which there are no surveys (4B, 4D-E, 4H and 4K). However, since they are a small proportion of the resource in a region with essentially no acid rain, and are largely underlain with the non-sensitive terrain of the Hudson's Bay lowland, the exclusion of this area does not affect the results of this analysis.

The watershed (2C-2M) in the region affected by precipitation of pH

4.5 or less are the most completely surveyed. Summaries presented below are for estimated total lake populations and are thus underestimated for watersheds and lake size categories where no surveys are available.

Fish Communities

Results obtained from the analysis of the survey data by fish community are similar to those of Johnson et al (1977) who used a subset of the surveyed lakes which had a fish fauna including one or more of walleye, northern pike, lake trout, and smallmouth bass. The average characteristics of the lakes containing the various communities are as expected (Figure 2, Table 9). Lakes containing brook trout only are the most common (1092), closely followed by the no game-fish type (1077). The lake trout - walleye community is the rarest (21) among the surveyed lakes.

A discriminant analysis on twenty fish community types produced results similar to those reported by Johnson et al (1977) (Table 10). The first discriminant function is heavily weighted for lake area while the second discriminant function is heavily weighted for maximum depth. The depth easily segregates lake trout lakes. Area differentiates the more complex fish communities from the less complex. There is generally a relationship between the size of a lake and the number of fish species found there. Brook trout communities (17 to 20) show a degree of isolation, particularly brook-trout only lakes (17) which are small lakes with a greater than average maximum depth. Centroids, calculated using the first two discriminant functions, are used to rank the 'distances' between communities and thereby a substitution table for missing values is obtained (Table 11).

The fish communities show patterns of geographic distribution. Lake trout communities are distributed in two regions of the province, namely in the northwest, particularly watersheds 5P and 5Q, and in the area of the Algonquin highlands through to Sault Ste. Marie, especially watersheds 2C-2E, 2H and 2K, which is the sensitive area of Ontario (Table 12). Centrarchids show a similar distribution. Brook trout occur mostly in the Algonquin highlands to the Sault Ste. Marie region (watersheds 2C, 2E and 2K) and on the northshore of Lake Superior (watershed 2B). The distributions of these species, though expanded in the past by introductions, are largely limited by climatic factors after limnological considerations.

The heat climate (degree-days) generally improves along a NE to SW gradient (Johnson et al 1977).

Lakes with no fish species are most closely associated with watersheds 2C, 4L and 2D (totalling 55%) where environmental effects of mining and smelting have already been noted (Table 12). Watersheds 2C and 2D are in the Sudbury region where most of the occurrences of no-fish lakes can be attributed to the local effects of atmospheric pollution, i.e., metal fallout and acid rain.

The fish community breakdown by lake-size categories is as expected (Table 13). Lakes with no fish or no game fish are mostly less than 10 hectares. Pike and lake trout lakes are the largest, with other groupings in between. Most of the brook-trout only category is between 10-100 hectares.

Acid Stress and Lake Sensitivity

Tallies according to the sensitivity classification (Table 4), and by lake size category, show the distributions by area of lakes (Tables 14 A-E). Tallies by the designated classes A-D (Table 15) indicate that there are 1213 lakes in class A (acidic); 3442 lakes in class B (impacted); 4186 lakes in class C (high risk); and 7248 lakes in class D (moderate risk). The majority of lakes in each class are less than 10 hectares in area.

The percentage distribution of each fish community in the stress-sensitivity matrix was determined and the results summarized by the designated class (Table 16). The presence/absence of different communities and the percentages are a guide to identifying the most severely stressed and endangered communities. As might be expected, most communities show no occurrence in class A; the exceptions being a small percentage of brook trout and bass lakes. Similarly, class B is poorly populated though a number of communities are represented. Most of the lakes appearing in classes A and B are located in watersheds 2C-E on the Sault St. Marie-Sudbury axis.

Classes C and D (Table 16) show those proportions of community types which may be considered at risk in the future. Brook trout, lake trout and bass communities represent the most exposed resources. Esocid and most percid communities are not considered to be at risk. The

community most in danger is the brook trout-lake trout-bass lakes with 63.4%, followed by lake trout-bass lakes with 37.6%.

DISCUSSION

The summaries indicate that there are over 1200 acidic lakes already incapable of sustaining a fish community and a further 3442 impacted lakes which are close to being in a similar condition. These lakes are mostly situated in watersheds 2C and 2E in the region of Sudbury. These numbers are consistent with figures reported by Beamish and Harvey (1972). They found that 33 of 150 lakes in the La Cloche area had a pH less than 4.5, and 37 had a pH in the range 4.5-5.5. A report by MOE (1978) on an extensive survey of lakes in the Sudbury region (watersheds 2C-2E) found 32 of 170 lakes had a pH less than 5.5, including 6 that had areas >1000 hectares. Scheider et al reported finding 3 lakes with a pH less than 5.5 out of 26 lakes in watershed 2E.

The summaries for the other classes indicate that there are 11434 (4186 + 7248) lakes that might become acidic. If the area of the province affected by acid rain increases, (this would be indicated by a northward movement of the pH 4.5 isopleth), a significantly larger number of lakes would also be at risk. Many of these lakes are small but do support a large proportion of the simpler fish communities.

Smaller sensitive lakes generally have smaller drainage areas, and have a smaller overall capacity to neutralise the acid rain. Therefore, smaller lakes can be expected to acidify more quickly. This has added significance when the fish communities are considered. Many of these smaller lakes contain brook trout communities which are an important recreational fishery in Ontario.

The non-lake trout communities most at risk must be considered in more immediate danger simply because they occur in smaller lakes. However, the overall picture indicates that lake trout communities represent a greater potential loss. The percentage potential losses will become even higher if the northwestern region of the province starts to receive acid rain. Should this happen, the majority of Ontario's lake trout, brook trout and bass community lakes will be in danger. Generally the northwestern lakes are more sensitive than the lakes currently exposed

to excess acid loading.

Given prevailing acid loadings to the southern and central regions of Ontario, we might expect to lose significant proportions of brook trout, brook trout x bass, bass, and bass x walleye communities during the 1980's. Further, we might expect to lose the lake trout associations with the above species over the next two decades. Losses of magnitude indicated in Tables 13 and 14 would mean an immense social and economic loss to the natural resource wealth of Ontario and Canada.

Table 1. Game fish community combinations

Community	Brook trout	Lake trout	Esocids	Centrarchids	Percids
0	NO FISH SPECIES RECORDED				
1	-	-	-	-	-
2	*	-	-	-	W
3	-	-	-	B	-
4	*	-	-	B	W
5	*	-	P	-	-
6	*	-	P	-	W
7	*	-	P	B	-
8	*	-	P	B	W
9	-	L	-	-	-
10	*	L	-	-	W
11	-	L	-	B	W
12	*	L	-	B	W
13	*	L	P	-	-
14	*	L	P	-	W
15	*	L	P	B	-
16	*	L	P	B	W
17	B	-	-	-	-
18	B	-	-	B	-
19	B	L	-	-	-
20	B	L	-	B	-

* present but rarely

- absent

Table 2. Comparison of estimated and 'known' frequency distributions

Watershed	Brook Trout		Lake Trout		Walleye	
	Surveyed	'Known'	Estimated	'Known'	Estimated	'Known'
2A	85	134	68	65	119	84
2B	174	503	130	127	404	149
2C	212	408	396	320	50	81
2D	51	54	118	117	112	108
2E	197	132	92	126	48	102
2F	30	20	0	1	4	11
2G	4	2	0	0	0	6
2H	76	71	85	122	47	88
2J	141	155	81	115	101	149
2K	295	367	184	214	55	96
2L	1	2	0	5	14	17
2M	11	8	11	23	6	16
4A	0	0	10	3	0	12
4B	0	0	0	0	0	0
4C	0	0	70	14	70	54
4D	0	0	0	0	0	27
4E	0	3	0	2	0	5
4F	0	2	0	2	734	31
4G	0	4	22	36	422	115
4H	0	0	0	0	0	5
4J	48	60	5	13	303	130
4K	0	0	0	0	0	0
4L	63	73	4	18	423	221
4M	88	80	10	21	141	102
4N	0	2	0	1	192	19
5P	2	6	261	256	713	289
5Q	18	24	218	176	510	287
5R	0	0	32	36	104	44
Total:	1496	2110	1797	2220	4578	3602

Table 3. Sensitivity categories with respect to conductivity and approximate alkalinity equivalents

Description	Conductivity $\mu\text{mho}/\text{cm}^2$ at 25C	Alkalinity meq/l
Very sensitive	0 - < 30	0 - < 0.2
Moderately sensitive	30 - < 50	0.2 - < 0.3
Sensitive	50 - < 70	0.3 - < 0.4
Unaffected	70+	0.4+

Table 4. Categories of lakes subject to stress from acid rain

RAIN pH	LAKE pH	LAKE CONDUCTIVITY			
		30	50	70	
5.5	6.5 —				
	6.0 —				
	5.3 —				
	4.7 —				
5.0	6.5 —				
	6.0 —				
	5.3 —				
	4.7 —				
4.5	6.5 —	D			
	6.0 —	C	D		
	5.3 —	B	B	B	B
	4.7 —	A	A	A	A
	6.5 —	D			
	6.0 —	C	D		
	5.3 —	C	C	D	
	4.7 —	B	B	B	B
		A	A	A	A

Table 5. Percentage data substitutions

Watershed	# of Lakes	% Conductivity	% pH
2A	279	54.5	2.9
2B	422	31.8	2.4
2C	571	73.0	6.3
2D	236	39.0	3.0
2E	673	18.9	5.6
2F	208	16.8	2.9
2G	69	26.1	2.9
2H	415	33.0	13.5
2J	510	39.0	12.7
2K	758	37.7	16.2
2L	51	31.4	17.6
2M	97	57.7	29.9
4A	1	-	-
4B	0	-	-
4C	1	-	-
4D	0	-	-
4E	0	-	-
4F	11	9.1	-
4G	67	11.9	-
4H	-	-	-
4J	296	10.8	8.8
4K	-	-	-
4L	455	17.1	2.0
4M	445	41.8	6.1
4N	10	10.0	-
5P	432	31.0	9.3
5Q	307	20.5	3.9
5R	11	-	-
Total	6325	34.3	8.0

Table 6. Frequency of lakes in inventory classified by colour, secchi depth and pH

Colour	Secchi (m)	pH						
<u>COLOURLESS</u>		4	5	6	7	8	9	
	0 - 1	0	0	0	14	22	10	1
	1 - 2	0	3	13	56	81	29	0
	2 - 4	2	9	55	353	289	94	1
	4 - 8	0	6	72	421	299	68	0
	>8	0	1	17	33	30	5	0
<u>YELLOW-BROWN</u>	0 - 1	2	1	15	33	81	37	4
	1 - 2	1	13	72	330	241	61	2
	2 - 4	0	12	155	918	511	75	4
	4 - 8	0	4	44	290	125	13	0
	>8	0	1	0	4	2	0	0
<u>BLUE-GREEN</u>	0 - 1	0	1	0	3	9	5	2
	1 - 2	0	2	1	18	24	10	1
	2 - 4	0	4	42	140	107	19	0
	4 - 8	0	15	85	415	188	26	0
	>8	1	14	9	46	19	4	0

Table 7. Fish community composition of likely Dystrophic Lakes

Secchi depth (m)	pH range	Total	Fish Community		
			No. fish	No. gamefish	Brook trout
0 - 1	<4	2	1	1	-
	4-5	1	1	-	-
	5-6	15	6	5	2
1 - 2	<4	1	1	-	-
	4-5	13	2	5	3

Table 9. Lake characteristics by fish community in Ontario

FCOM	Area (HA)	Shoreline (KM)	%-Max (M)	%-Mean (M)	Elevation (M)	pH	Conductivity
NONE- N	230	230	228	203	187	221	123
MIN	1.0	.2	.1	.1	214.0	3.7	9.2
MEAN	40.5	3.4	10.0	3.8	342.1	6.6	155.0
MAX	2512.5	80.0	90.2	24.0	518.0	9.6	566.0
----- N	1077	1076	1077	1045	888	1012	747
MIN	1.0	.2	.2	.2	201.0	3.9	6.9
MEAN	31.4	3.1	10.8	3.8	343.9	6.9	111.0
MAX	1503.3	124.1	61.8	20.7	610.0	9.5	611.1
*---N N	63	63	63	62	53	57	39
MIN	2.3	.7	.7	1.0	204.0	5.5	13.4
MEAN	207.3	9.7	14.5	5.1	323.9	7.0	94.3
MAX	6319.1	154.7	62.5	18.8	433.0	8.8	419.4
---B- N	384	382	384	382	325	345	285
MIN	1.0	.5	.8	.3	206.0	4.4	16.3
MEAN	61.6	5.0	11.3	4.1	316.3	6.8	116.5
MAX	906.5	68.0	43.8	17.5	511.0	9.4	689.7
*--BW N	58	58	58	58	49	57	44
MIN	1.7	.5	1.7	.6	201.0	4.9	21.1
MEAN	168.1	11.1	14.6	5.4	292.9	6.7	73.1
MAX	991.2	44.6	66.7	27.3	473.0	8.5	330.1
*-P-- N	720	719	720	703	569	670	504
MIN	1.0	.2	.5	.2	204.0	4.0	10.8
MEAN	124.9	7.3	12.0	3.8	343.6	7.2	123.6
MAX	5674.5	263.8	54.8	15.3	549.0	9.4	717.0

Table 9. Lake characteristics by fish community in Ontario (Cont.)

FCOM	Area (HA)	Shoreline (KM)	%-Max (M)	%-Mean (M)	Elevation (M)	pH	Conductivity
*-P-W N	799	797	799	795	689	767	652
MIN	1.5	.5	.8	.5	213.0	5.3	15.3
MEAN	889.3	26.0	14.2	4.3	345.7	7.3	96.7
MAX	79833.5	732.2	97.0	45.1	549.0	9.4	404.2
*-PB- N	252	251	252	250	136	221	154
MIN	2.0	.5	.5	.1	201.0	4.4	22.1
MEAN	169.3	10.3	13.2	4.6	286.2	7.2	172.2
MAX	5348.5	178.5	67.0	20.5	468.0	8.9	663.6
*-PBW N	337	337	337	330	216	283	184
MIN	2.7	.7	1.5	.6	201.0	4.5	22.4
MEAN	639.0	26.2	16.4	5.3	309.2	7.0	103.4
MAX	10025.5	264.1	67.0	21.1	610.0	9.4	455.6
-L--- N	325	325	325	323	303	308	223
MIN	1.7	.5	2.0	1.2	207.0	5.1	18.8
MEAN	193.0	11.3	30.4	10.1	370.0	6.6	57.4
MAX	2023.0	103.0	91.5	39.6	503.0	8.3	290.0
*L---W N	21	21	21	21	21	20	10
MIN	32.3	3.6	13.0	4.5	227.0	5.6	24.5
MEAN	892.8	29.6	42.0	15.4	377.3	6.7	59.8
MAX	10537.6	193.0	102.7	42.7	451.0	8.4	121.5

Table 9. Lake characteristics by fish community in Ontario (Cont.)

FCCOM	Area(HA)	Shoreline(KM)	%-Max(W)	%-Mean(M)	Elevation(M)	pH	Conductivity
-L-B- N	170	170	170	169	159	149	111
MIN	10.3	2.0	9.1	3.0	203.0	4.4	4.0
MEAN	299.3	14.4	33.0	11.3	326.0	6.6	62.3
MAX	3864.6	89.8	87.5	30.6	448.0	7.9	215.3
*L-BW N	29	29	29	29	26	24	14
MIN	41.8	3.1	21.3	6.2	215.0	5.5	30.7
MEAN	579.1	26.1	37.9	12.1	300.2	6.5	69.0
MAX	2545.0	88.7	70.1	26.5	397.0	7.3	174.9
*LP-- N	146	146	146	146	137	134	101
MIN	40.7	2.3	12.1	4.1	217.0	4.6	16.9
MEAN	789.8	28.2	39.3	12.5	391.3	6.9	58.4
MAX	10913.5	280.0	162.8	48.7	496.0	8.6	223.7
*LP-W N	110	110	110	109	107	96	73
MIN	11.6	1.3	16.1	3.5	267.0	6.0	18.9
MEAN	2495.3	73.7	45.2	12.9	369.0	7.0	62.8
MAX	34833.8	641.7	186.0	39.1	479.0	8.4	241.9
*LPB- N	79	79	79	78	59	71	39
MIN	29.6	3.0	10.0	4.0	200.0	5.3	23.2
MEAN	1014.5	36.1	38.5	12.0	306.2	6.9	87.3
MAX	11194.3	299.2	97.2	34.3	439.0	8.3	277.1

Table 9. Lake characteristics by fish community in Ontario (Cont.)

FCOM	Area (HA)	Shoreline (KM)	%-Max (M)	%-Mean (M)	Elevation (M)	pH	Conductivity
*LPB N	92	92	92	89	83	80	57
MIN	25.0	2.8	8.1	3.7	210.0	5.1	21.8
MEAN	2430.5	75.2	45.8	13.0	330.8	6.8	62.9
MAX	29507.1	653.2	213.5	41.1	461.0	7.9	217.3
B---- N	1092	1092	1092	1075	943	1000	615
MIN	1.0	.1	.8	.3	201.0	4.0	6.4
MEAN	26.9	2.9	13.5	4.7	374.2	6.7	90.2
MAX	975.3	33.2	65.8	20.8	595.0	9.9	547.1
B--B- N	75	74	75	74	71	65	50
MIN	2.5	.5	2.0	.8	204.0	4.5	27.6
MEAN	58.5	4.4	13.2	4.9	336.4	6.7	121.5
MAX	688.7	31.1	32.5	15.0	458.0	8.9	489.7
BL--- N	227	227	227	225	200	210	103
MIN	4.8	.2	4.8	1.3	207.0	4.7	23.7
MEAN	193.6	10.7	27.2	8.9	384.3	6.6	47.2
MAX	2427.5	71.3	73.1	23.8	519.0	8.5	245.4
BL-B- N	39	39	39	39	38	32	25
MIN	23.0	2.0	14.0	4.0	211.0	5.5	25.9
MEAN	771.4	26.3	36.6	11.8	354.2	6.4	40.8
MAX	7058.0	170.5	73.1	38.6	443.0	7.7	73.3

Table 10. Results of discriminant analysis on twenty fish communities

Statistics	Canonical roots			
	1	2	3	4
Eigen value	1.222	0.338	0.119	0.029
χ^2	6210.2	2228.0	776.7	215.2
df	95	72	51	32

Canonical coefficients

Area (loge)	0.908	-	0.416	not calculated
Maximum depth (loge)	0.159		0.926	" "
Conductivity (loge)	0.046	-	0.115	" "
Elevation	-0.124		0.372	" "
pH	0.171	-	0.090	" "

Table 11. Substitution preferences for missing data by fish community

Fish Community	Substitute fish community in order of preference																			
0/1	3	18	17	5	2	7	4	19	9	6	11	8	20	15	12	10	13	16	14	
2	5	4	3	7	18	6	8	1	11	17	9	19	15	20	12	13	10	16	14	
3	5	18	2	1	7	4	17	6	8	19	9	11	20	15	12	13	10	16	14	
4	7	2	5	6	8	3	18	15	11	1	12	20	9	19	17	16	13	10	14	
5	3	2	7	4	18	1	6	8	17	11	9	19	15	20	12	13	10	16	14	
6	8	7	4	2	5	15	3	12	16	11	18	20	14	13	9	10	19	1	17	
7	4	5	2	6	3	8	18	1	15	11	17	12	9	20	19	16	13	10	14	
8	6	4	7	2	15	5	12	16	3	11	14	18	20	13	9	10	19	1	17	
9	19	20	11	10	13	12	15	18	2	17	4	16	14	3	5	7	8	6	1	
10	13	20	11	12	9	15	19	14	16	2	4	18	8	6	5	3	7	17	1	
11	20	9	13	10	12	15	19	16	14	2	4	18	8	6	5	3	7	17	1	
12	15	13	11	20	16	14	10	9	19	8	6	4	2	7	18	5	3	17	1	
13	10	12	20	11	15	14	9	16	19	8	4	2	6	18	7	5	3	17	1	
14	16	12	15	13	10	20	11	8	9	6	19	4	2	7	5	18	3	17	1	
15	12	16	11	13	20	14	10	9	8	6	19	4	2	7	5	18	3	17	1	
16	14	15	12	13	11	10	20	8	6	9	4	19	2	7	5	18	3	17	1	
17	1	18	3	5	2	19	9	4	7	11	20	10	15	6	13	12	8	16	14	
18	3	5	2	1	17	4	7	19	9	11	6	20	8	15	12	10	13	16	14	
19	9	20	11	10	13	12	18	16	17	2	3	4	5	16	14	1	7	8	6	
20	11	10	13	9	12	19	15	16	14	2	4	18	8	6	5	3	7	17	1	

Table 12. Percentage distribution of fish communities by watershed

MS	NONE-	-----	*---W	---B-	*--BW	*-P--	*-P-W	*-PB-	*-PSW	-L---	*L--W	-L-B-	*L-BW	*LP--	*LP-W	*LPB-	*LPBW	B----	B--B-	BL---	BL-B-
2A	9.	9.	3.	9.	5.	20.	10.	5.	9.	4.	3.	-	1.	26.	3.	-	19.	4.	7.	1.	-
2B	9.	14.	19.	3.	1.	3.	4.	-	-	9.	-	2.	-	3.	2.	-	2.	21.	1.	14.	1.
2C	27.	11.	-	9.	7.	5.	1.	8.	-	22.	4.	21.	47.	4.	-	11.	2.	15.	15.	30.	11.
2D	11.	4.	7.	8.	16.	1.	-	3.	5.	4.	-	3.	19.	2.	1.	8.	20.	7.	7.	2.	-
2E	2.	4.	1.	28.	24.	-	-	14.	11.	2.	-	26.	1.	-	-	13.	3.	10.	30.	4.	52.
2F	-	-	-	1.	2.	-	-	2.	-	-	-	-	-	-	-	-	-	3.	3.	-	-
2G	-	1.	-	3.	5.	-	-	2.	-	3.	-	-	12.	-	-	-	-	16.	7.	-	5.
2H	1.	1.	-	16.	3.	-	-	13.	12.	7.	-	22.	12.	-	-	1.	-	2.	7.	1.	-
2J	5.	4.	7.	1.	1.	2.	1.	2.	4.	6.	2.	1.	15.	-	-	1.	7.	9.	2.	9.	-
2K	-	4.	1.	10.	6.	-	-	7.	6.	-	-	18.	-	-	-	3.	4.	23.	11.	35.	32.
2L	-	-	-	1.	-	-	-	2.	4.	-	-	-	-	-	-	1.	-	-	-	-	-
2M	-	-	-	2.	-	-	-	17.	3.	-	-	-	-	15.	-	15.	-	-	-	-	-
4A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44.	-	-	-	-	-	-
4C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4F	-	-	-	-	-	15.	13.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4G	-	4.	29.	-	-	24.	21.	-	-	-	27.	-	-	4.	9.	-	-	-	-	-	-
4H	-	-	-	-	-	-	-	-	2.	-	-	-	-	-	3.	-	-	3.	-	-	-
4J	9.	7.	5.	-	-	6.	7.	-	-	-	-	-	-	1.	-	-	-	-	-	-	-
4K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4L	17.	5.	4.	-	-	7.	7.	-	-	2.	-	-	-	1.	-	-	-	2.	-	-	-
4M	3.	2.	2.	-	-	3.	7.	-	-	1.	-	-	-	-	-	-	-	3.	-	-	-
4N	3.	3.	-	-	-	-	2.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5P	-	7.	11.	8.	9.	7.	10.	16.	23.	16.	9.	7.	4.	28.	15.	38.	23.	-	-	-	-
5Q	5.	10.	11.	-	24.	7.	15.	9.	15.	23.	5.	-	-	15.	18.	10.	19.	1.	-	4.	-
5R	-	12.	-	-	-	-	3.	-	-	-	50.	-	-	-	4.	-	-	-	-	-	-

Table 13. Fish community by size category

Community	1000 HA	100 HA	10 HA		Total
NONE-	18.8	3.3	28.2	49.7	89830.1
-----	1.6	15.2	39.4	43.8	450587.7
*---W	29.4	22.0	43.6	4.9	45322.8
---B-	--	27.5	51.3	21.2	67492.9
*--BW	--	58.2	38.4	3.4	21078.5
*-P--	17.4	14.1	60.3	8.2	810650.9
*-P-W	59.3	32.2	8.4	.1	2119844.5
*-PB-	23.2	39.4	32.2	5.2	96947.5
*-PBW	69.6	22.8	7.4	.2	476883.8
-L---	10.3	42.1	46.6	.9	189621.5
*L--W	29.6	67.2	3.2	--	81303.4
-L-B-	44.2	41.2	14.6	--	102747.2
*L-BW	63.7	32.0	4.3	--	35085.8
*LP--	71.4	23.6	4.9	--	395180.6
*LP-W	91.4	8.5	.1	--	1048449.2
*LPB-	83.0	14.4	2.5	--	212732.7
*LPBW	91.1	8.5	.4	--	521160.5
B----	--	36.8	55.3	7.9	41637.4
B--B-	--	57.5	40.3	2.2	6233.2
BL---	32.4	54.2	13.4	.1	62420.2
BL-B-	75.9	22.1	2.0	--	42717.6
TOTAL	55.6	22.6	16.9	4.9	6917928.0

Table 14A. Summary for size class ≥ 1000 (HA)

Rain pH	Lake pH	Lake Conductivity		
		30	50	70
5.5	6.5	--	469519.5	12241.4
	6.0	--	--	184813.1
	5.3	--	--	--
	4.7	--	--	--
	4.5	--	--	--
	4.0	--	--	--
5.0	6.5	139389.0	604462.7	421330.4
	6.0	27076.8	70398.2	346522.1
	5.3	--	3774.0	37155.4
	4.7	--	6936.2	--
	4.5	--	--	--
	4.0	--	--	--
4.5	6.5	--	73721.7	217369.7
	6.0	--	--	587729.5
	5.3	--	8303.7	8692.9
	4.7	--	1411.6	--
	4.5	--	--	--
	4.0	--	--	--
4.0	6.5	--	82640.7	167806.9
	6.0	--	93195.6	229795.3
	5.3	--	22657.6	2377.9
	4.7	--	15594.7	--
	4.5	--	10206.6	--
	4.0	--	826.8	--
3.5	6.5	--	--	--
	6.0	--	--	--
	5.3	--	--	--
	4.7	--	--	--
	4.5	--	--	--
	4.0	--	--	--

Table 14B. Summary for size class <1000--100 (HA)

Rain pH	Lake pH	30	Lake Conductivity 50	70
	6.5	--	--	--
	6.0	--	--	--
	5.3	--	--	--
	4.7	--	--	--
5.5				147998.0
	6.5	46324.1	222150.3	144829.1
	6.0	71232.7	56633.0	12601.3
	5.3	873.1	1994.0	1272.0
	4.7	--	761.0	--
5.0				
	6.5	4809.0	26853.5	43033.3
	6.0	1366.6	7201.1	950.1
	5.3	--	216.1	--
	4.7	--	--	--
4.5				
	6.5	1546.0	47835.1	66542.8
	6.0	6534.3	52689.3	25669.3
	5.3	2593.4	10871.9	7370.7
	4.7	--	1946.0	3001.6
		--	393.0	1279.8

Table 14C. Summary for size class <100--10 (HA)

Rain pH	Lake pH	30	Lake Conductivity 50	70
	6.5	--	--	55378.5
	6.0	--	--	54808.5
	5.3	--	--	--
	4.7	--	--	--
5.5		--	--	--
	6.5	27506.0	102743.6	30878.5
	6.0	19611.6	18209.9	215502.0
	5.3	1679.1	10184.2	1615.8
	4.7	--	560.4	287.8
5.0		--	--	--
	6.5	3677.5	22819.7	36178.8
	6.0	5056.6	11856.7	273540.3
	5.3	1663.6	1667.4	3302.4
	4.7	--	--	6845.1
4.5		96.7	--	4356.2
	6.5	1816.0	34395.3	45026.5
	6.0	6659.5	29075.2	59101.7
	5.3	3631.1	12376.3	32415.9
	4.7	358.9	1451.4	12766.8
		--	371.4	2275.6
			293.1	1599.0
				2759.5

Table 14D. Summary for size class <10--1 (HA)

Rain pH	Lake pH	30	Lake Conductivity 50	70
	6.5	--	--	--
	6.0	--	--	--
	5.3	--	--	--
	4.7	--	--	--
5.5				
	6.5	24156.8	6283.6	11.5
	6.0	6414.4	12642.8	13.6
	5.3	--	--	--
	4.7	--	--	--
5.0				
	6.5	6655.7	7565.0	8602.4
	6.0	4819.8	156.5	5064.4
	5.3	392.4	301.7	432.0
	4.7	115.9	--	--
4.5				
	6.5	975.5	6906.1	16842.8
	6.0	3889.6	7136.1	12374.3
	5.3	2132.9	6249.0	6877.9
	4.7	666.7	771.0	4417.0
		195.8	--	2580.3

Table 14E. Summary for total (HA)

Rain pH	Lake pH	30	Lake Conductivity 50	70
	6.5	--	469519.5	67619.9
	6.0	--	--	--
	5.3	--	--	--
	4.7	--	--	--
5.5		--	--	--
	6.5	237375.9	935640.2	597049.5
	6.0	124335.5	157884.0	51386.2
	5.3	2552.2	15952.3	8208.3
	4.7	--	1321.5	--
5.0		--	--	--
	6.5	15142.2	130960.0	305184.2
	6.0	11243.0	19214.3	17620.6
	5.3	2056.1	3596.8	432.0
	4.7	115.9	--	--
4.5		96.7	--	--
	6.5	4337.6	171777.2	295919.0
	6.0	17083.4	182096.2	93117.0
	5.3	8357.5	45091.8	37222.0
	4.7	1025.6	4995.2	11745.0
		195.8	764.5	4153.2

4768.4

Table 15. Areas and numbers of lakes in the Stress-Sensitivity Classes

Class	Rain pH	Lake		1000		ha		1000		ha		1000		Total	
		Cond.	pH	Area	#	Area	#	Area	#	Area	#	Area	#	Area	#
A	<4.5 4.5-5.0	-	<4.7 "	0	0	2150	8	3224	127	4308	7	9786	1213		
		-		0		0		97		0				0	
		Total:		0		0		3321		0				0	
B	<4.5 4.5-5.0	-	4.7-5.3 "	0	0	4948	20	7736	297	11723	780	25187	3442		
		-		0		0		0		0					
		Total:		0		0		4948		0				0	
C	<4.5 " " 4.5-5.0	<30	5.3-6.0 6.0-6.5 5.3-6.0 5.3-6.0	0	0	2593	83	3631	935	2133	392	72589	4186		
		"		0		6534		6660		3890					
		30-50		15595		10872		12376		6249					
D	<4.5 " " 4.5-5.0	<30	>6.5 6.0-6.5 5.3-6.0 6.0-6.5 5.3-6.0	0	0	1546	262	1816	1937	976	320	238497	7248		
		30-50		93196		52689		29075		7136					
		50-70		10207		7371		12767		6878					
A-D	<4.5 " " 4.5-5.0	<30	6.0-6.5 5.3-6.0 6.0-6.5 5.3-6.0	0	0	1367	373	5057	3296	4820	49594	346059	16089		
		30-50		1412		216		1667		320					
		Total:		104814		63189		262		50382				1937	20112
			Total:	120409	25	90286	373	85770	3296	49594	12395	346059	16089		

Table 16. Percent fish community exposure by Stress-Sensitivity Class

Fish Community	A	B	C	D	Area ha
NONE-	<u>4.7</u>	<u>10.6</u>	<u>11.0</u>	4.9	89830
-----	0.6	2.2	3.3	6.1	480587
*---W	-	-	2.5	2.5	45322
---B-	0.3	0.8	<u>15.1</u>	<u>16.7</u>	67493
*--BW	-	0.6	<u>6.2</u>	<u>16.6</u>	21079
*-P--	-	0.2	-	0.5	810651
*-P-W	-	-	-	-	2119844
*-PB-	0.3	0.7	2.5	3.9	96947
*-PBW	-	0.2	0.4	6.7	476883
-L---	-	-	3.4	<u>10.9</u>	189622
*L--W	-	-	-	1.6	81303
-L-B-	0.4	0.2	<u>11.5</u>	<u>26.1</u>	102747
*L-BW	-	-	<u>12.6</u>	<u>19.9</u>	35085
*LP--	-	-	-	1.8	395180
*LP-W	-	-	-	0.4	1048449
*LPB-	-	-	0.4	2.9	212733
*LPBW	-	0.4	0.2	5.1	521161
B----	0.3	0.9	<u>7.0</u>	<u>15.4</u>	41637
B--B-	2.0	0.8	<u>18.7</u>	<u>14.3</u>	6233
BL---	-	0.2	1.9	<u>25.8</u>	62420
BL-B-	-	-	1.9	<u>61.5</u>	42718

Figure 1. Secondary Watersheds in Ontario and precipitation pH isopleths.

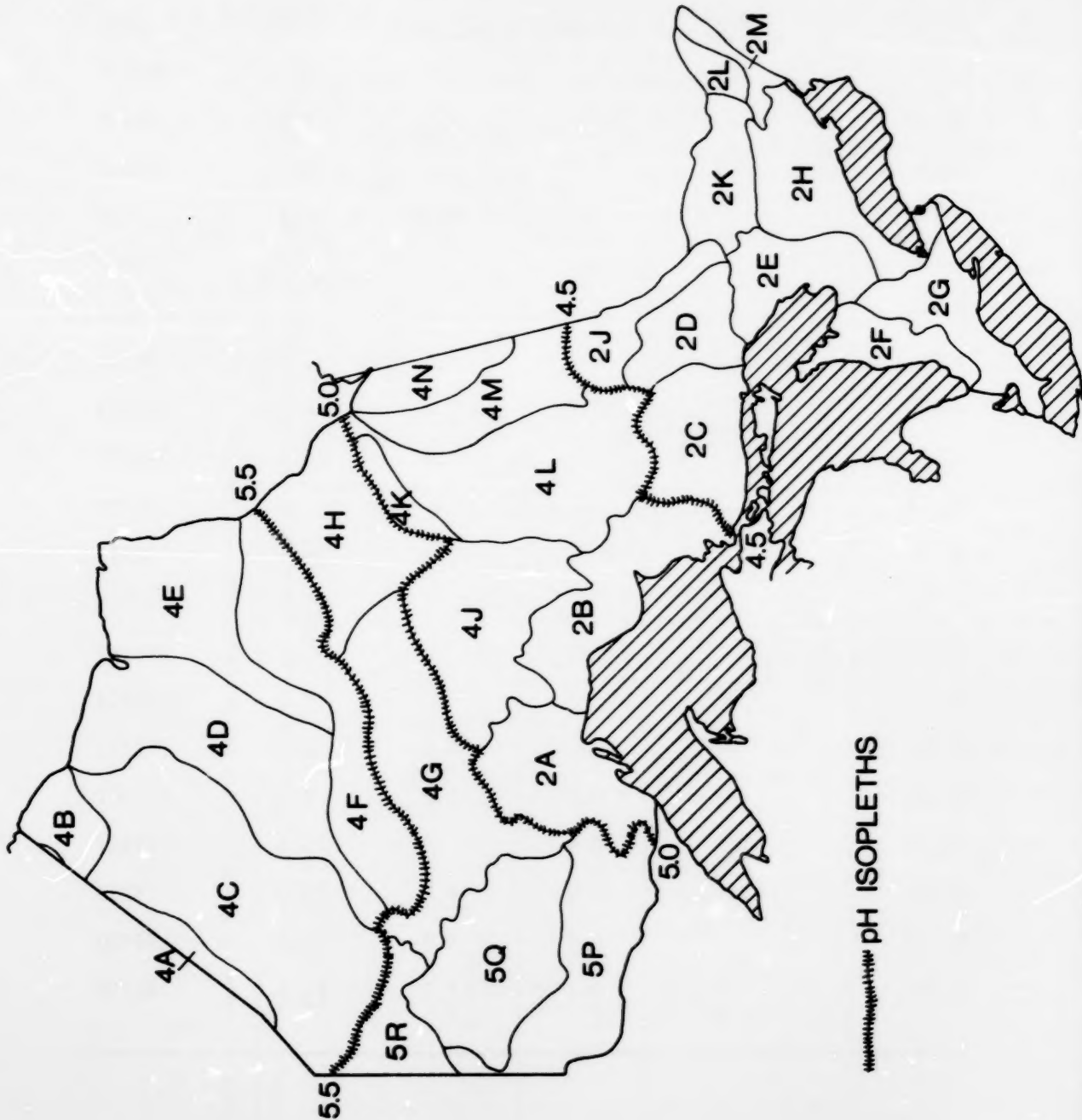


Figure 2. Mean Characteristics of Lake Inventory Lakes by Fish Community

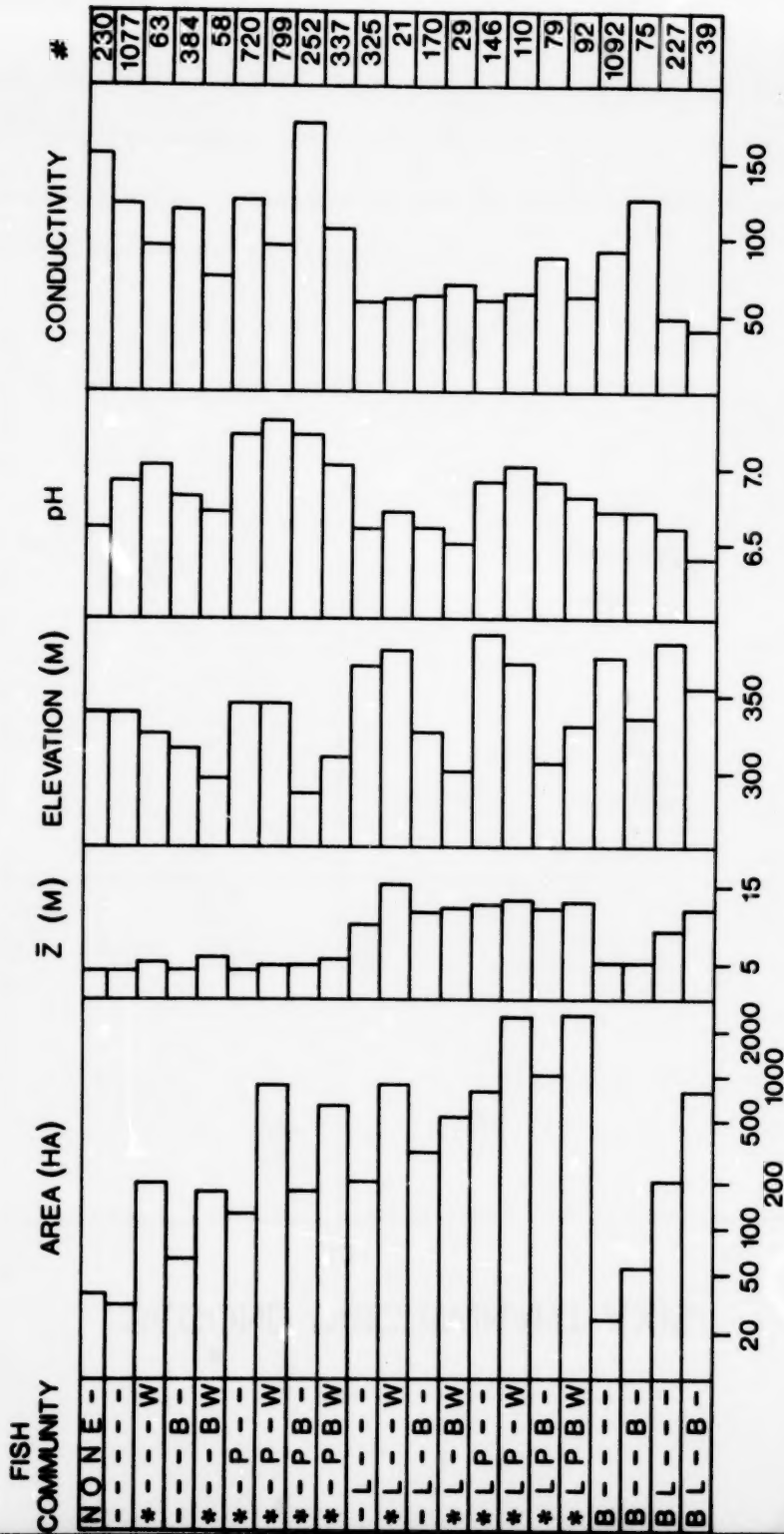
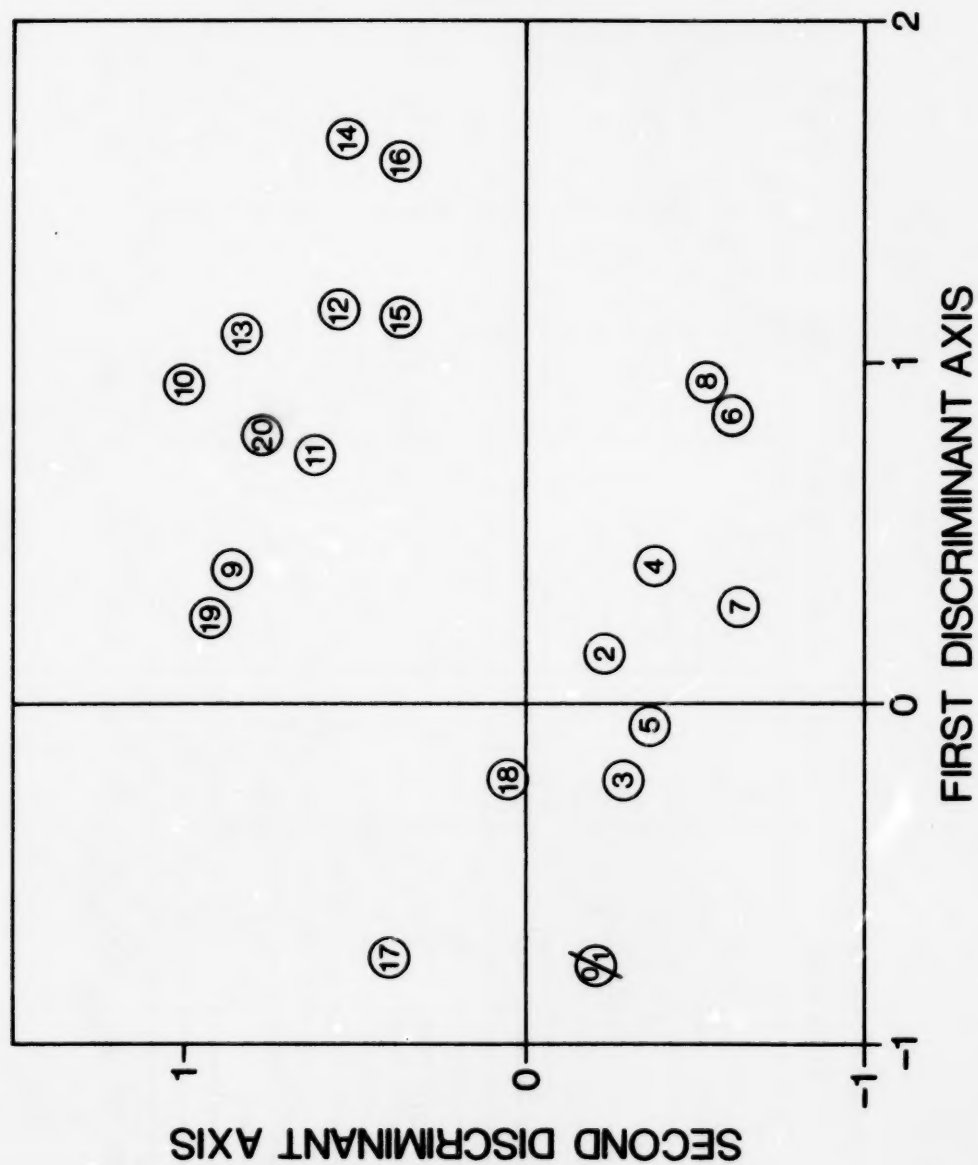


Figure 3. Fish Community Centroids on the First Two Discriminant Axis



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